THE FUNCTION OF THE HYALOID CANAL AND SOME OTHER NEW POINTS IN THE MECHANISM OF THE ACCOMMODATION OF THE EYE FOR DISTANCE.

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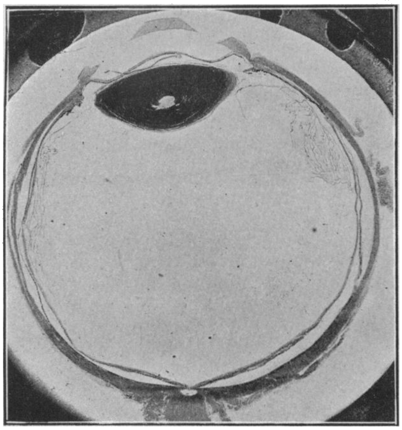
For the purposes of this paper I do not require to discuss the question of the form assumed by the lens during positive accommodation, whether its surfaces remain more or less spherical or become markedly conical. I start from the fact, first shown by Helmholtz, that during positive accommodation the suspensory ligament of the lens is slackened[1].

If the ox eye be left to spontaneously decompose, as was described by Aeby in 1882, but independently demonstrated by me and used in my practical classes since 1885, and if the mass which escapes from the opened sclerotic and choroid, viz. the vitreus, suspensory ligament, and lens in its capsule, all in an united mass, the "eye-nucleus," be washed, stained and examined, no detachment of the suspensory ligament from the vitreus during the necessary manipulations is ever seen: this is a union of the greatest firmness, and all this is in favour of the views of those authors who, like Salzmann (quoted very fully in Merkel and Bonnet's *Ergebnisse*, 1900), make the zonula arise out of the vitreous substance, with a true interlacement of the zonular and vitreous fibrillæ. If the account given by G. Retzius[2] is correct, the hyaloid of the vitreus passes on to the pars ciliaris retinæ. In that case these fibrils of the suspensory ligament would be attached partly to the deep face of the hyaloid in this region, but partly also to the very substance of the vitreus, springing out of it near the ora serrata. We have in this connection the reason why a shrinking vitreus readily separates from the retina, except at the ora serrata. In any case, however, there is this very firm union of the suspensory ligament to the

[1] On this point see Article by Lovén, *Ergebnisse der Physiol.*, 1903. Also Grossmann, *Brit. Med. Journ.*, Sept. 26, 1903. My own work supports their conclusions.

[2] *Biologische Untersuchungen*, 1894.

vitreus, and that is my main point in the meantime. This also is no mere superficial union, for the deep surface of the hyaloid is here attached to a very complete and well-marked network of fibrous membranes, which pass into the vitreous substance in a ring in the anterior and outer part of the vitreous body. These membranes have been described by various authors, but I cannot find that any distinct office has been assigned to them. A rough dissection of the vitreus, as by squeezing it between the finger and thumb, suffices to show the existence of this ring of fibrous membranes, and their general arrangement in sections may be seen even by the naked eye (Figs. 1 and 2). They form a complicated network, densest immediately under the hyaloid, and are gradually lost as they pass inwards and backwards. The interstices are filled with the vitreous substance, and the membranes themselves, described by Retzius as condensations of the proper vitreous fibrils, look like white fibrous tissue, and this may in part at least account for the gelatine obtained from the vitreus by boiling.



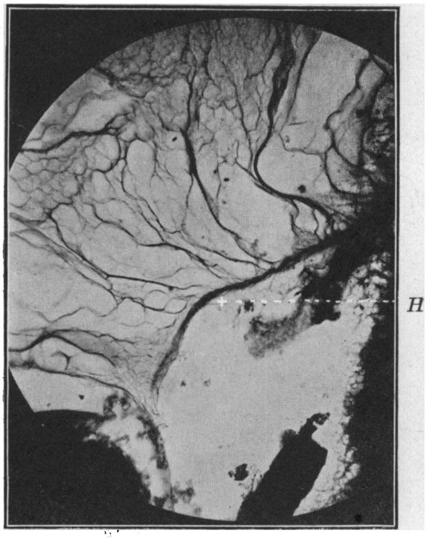
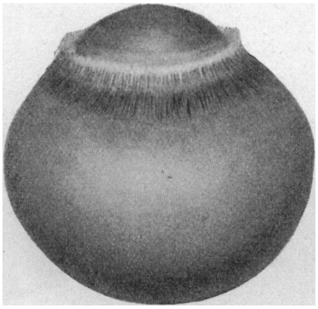
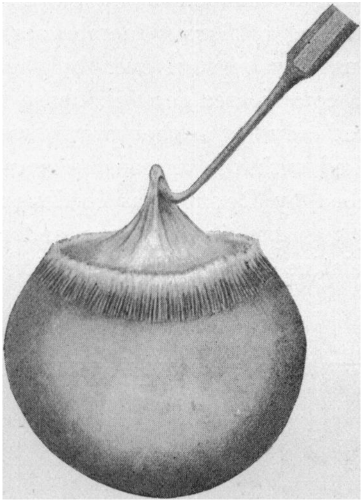


Fig. 1. Photograph of horizontal section of human eye, × 3½ : celloidin. Shows ring of fibrous membranes in the antero-external region of the vitreus.

Fig. 2. Photograph of fibrous membranes in the vitreus, × 18 : celloidin. Same section as Fig. 1. *H*, hyaloid.

If in an eye-nucleus the suspensory ligament be divided nearly all the way round the lens, and if the preparation be now held up by the lens, the whole weight of the mass is supported by the band of undivided suspensory ligament. Further, this band may support in addition a considerable amount of traction before it ruptures, even in the more or less decomposed eye. Thus I found that a band 1 mm. wide in such decomposed ox eyes sustained on an average no less than 12 grammes. It is clear therefore that the fibres of the suspensory ligament by which it is attached to the vitreous body are fairly strong. But these vitreous fibres must be attached to a structure at least as strong as themselves: if attached to the hyaloid only, this membrane





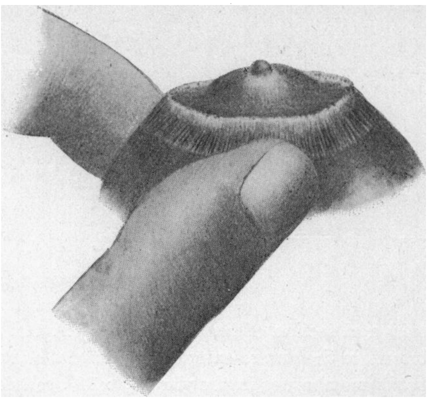


Fig. 3. Ox eye-nucleus, showing the tufts of the ciliary fibres on the suspensory ligament.

Fig. 4. Ox eye-nucleus, with the patellar membrane punctured and raised on a blunt hook.

Fig. 5. Ox eye-nucleus, compressed to project the thin central portion of the patellar membrane, through a puncture in which a pimple of vitreous substance projects. The thick resistant marginal portion behind the canal of Petit is seen too.

by itself would not stand the strain, but the hyaloid having attached to its deep surface in the ciliary zone the membranes of the vitreus, and these being embedded in the vitreous substance, like the roots of a plant in the ground, the pull of the vitreous fibres of the suspensory ligament—how this is produced will be afterwards described—is distributed over a large part of the vitreous body itself, especially in its antero-peripheral zone, and so the hyaloid is shielded.

In the eye-nucleus the surface of the suspensory ligament may with the naked eye, still better with a hand-lens, be seen to have on its surface a circle of tufts of an elongated form and converging towards the optic axis (Fig. 3). These tufts in unstained preparations are like cotton-wool in appearance, and are made up of the networks of fine fibrils which constitute the attachment of the suspensory ligament to the ciliary bodies, the tufts having come out of the valleys between the bodies. Behind the tufts is a band of fibrils which is not raised into tufts—this corresponds to the orbiculus ciliaris. The diagram (Fig. 6)

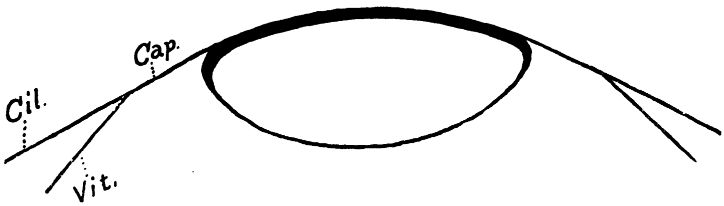


Fig. 6. Scheme of the three parts of the suspensory ligament, viz. the vitreous attached to the vitreous body, the ciliary attached to the orbiculus ciliaris and ciliary processes, and the capsular made up of the vitreous and ciliary and attached to the lens capsule.

shows the three portions out of which the ligamentum suspensorium may thus be regarded as being built up, and the name of each is chosen according to its immediate attachment.

For the better understanding of the subject I have found it profitable to make a model (Fig. 7) of the parts thus: nail one end of a flattened rubber band about 4 inches long to a board; tie the two sides of the band firmly together about their middle; cut the free end and after stretching it to a moderate extent nail one of the cut ends to the board. The band is thus stretched between the double end and one of the single ones and one end is free. The whole represents the suspensory ligament; the double piece represents the part attached to the lens capsule, the capsular portion: the single end nailed down represents the portion of the ligament attached to the vitreus; the free end grasped between finger and thumb represents the portion attached to the ciliary bodies, &c.; pulling this last portion outwards and letting it recoil inwards obviously represents the effect of the relaxation and contraction of the ciliary muscle. It will be seen that

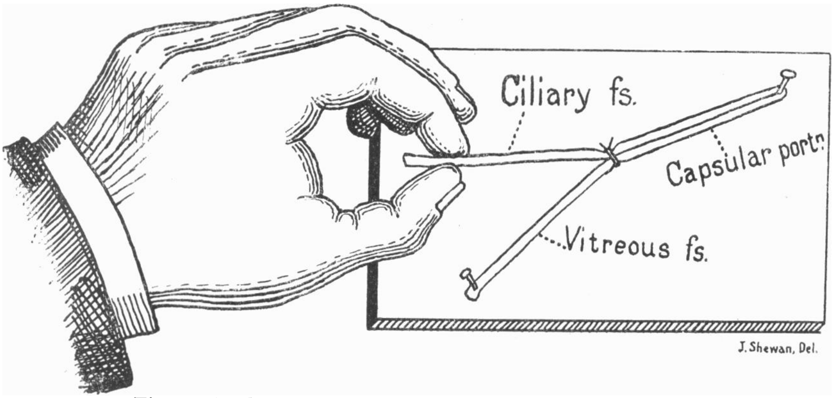


Fig. 7. Model of the three parts of the suspensory ligament.

as the capsular portion of the suspensory ligament is tensed, by tensing the ciliary portion, the vitreous portion is affected in just the opposite sense. Briefly the tension of the vitreous portion is necessarily varied during accommodation. In positive accommodation the vitreous portion will be dragged forwards and inwards by the capsular and thus its tension increased. It is true that the tremor of the lens during extreme positive accommodation, and during the action of eserin, shows that even when the vitreous fibres are most tense that tension is not great. At the same time, excepting the adhesion of the posterior layer of the lens-capsule to the patellar vitreous membrane, the tension of these fibres all round the lens is the only force which there is to maintain the lens in its place during the slackening of the suspensory ligament, so that it probably has some value. And that the vitreous fibres may be considerably tensed may be argued from their strength as detailed above, for the strength of a ligament in the body is proportioned to the strain which it may have to bear.

The functions of these two portions of the suspensory ligament are entirely different, the ciliary portion virtually is the tendon of the ciliary muscle and permits movement, while the vitreous portion, playing the part of a ligament, limits movement. The mere facts that the vitreous fibres are the sole means, excepting the before-mentioned adhesion of the lens-capsule to the patellar membrane, by which the lens is held in its place in extreme positive accommodation, during the action of eserin and in the eye-nucleus, demonstrate this ligamentous function. The need for some arrangement of this nature has indeed been generally recognised, and the office is assigned to the ciliary fibres alone, but the study of the conditions in the eye-nucleus simplifies the whole subject, it just divides it by 2, and we study the vitreous apart from the ciliary fibres.

When the ciliary muscle contracts, it admittedly (most authors) slackens the ciliary part of the suspensory ligament, and thus permits the lens to bulge forwards, but at the same time it stretches the choroid and thus the name tensor choroideæ given to the muscle. When it relaxes, it is the recoil of the choroid that pulls the ciliary part of the ligament backwards. This movement of the choroid was demonstrated experimentally by Hensen and Völckers. There is thus a perpetual struggle between the elasticity of the lens in its capsule and that of the choroid, and it is the ciliary muscle which introduces the variable vital factor, and gives the one or the other the upper hand: the pull of the choroid is more powerful than that of the unaided lens in its capsule, as is seen in negative accommodation. The perichoroidal lymph-space permits this movement of the choroid. One of the difficulties in accepting the Helmholtz theory has been to explain how negative accommodation, due to the relaxation of a muscle, is more quickly performed than the act of positive accommodation, due to its contraction. But it is obvious that negative accommodation is *not* carried out by the relaxation of the muscle—it is caused by the elastic recoil of the choroid, and therefore, being an elastic recoil, is quick.

Another difficulty has been the action of the circular fibres of the ciliary muscle. The radiating fibres slacken the suspensory ligament by pulling forwards its external attachment, but do not the circular fibres produce precisely the same effect by constricting the mouth of the choroid cup to which the suspensory ligament is attached externally? The ultimate effect of both parts is thus the same. Why then should there *be* two parts? The reason is, I believe, as follows: each portion of the radiating fibres is attached to its origin anteriorly more or less independently of the other parts, so that each part may act more or less independently of the others, and, if independently, then more or less irregularly, so that in the normal lens if radial fibres alone were present more or less irregularity of curvature would almost certainly arise and, therefore, dioptric imperfection. Where the greatest effort is required, as in hypermetropes, there the greatest development of these radial fibres is admittedly found. But here also is found the greatest development of the circular fibres—why? The circular fibres having no fixed point of origin external to their own circle must necessarily act more evenly than the radial fibres—any uneven action is immediately passed on around the circle. But it is just where the greatest efforts are made that the greatest irregularities are most likely to occur, and thus in hypermetropes these fibres also are most highly developed for the double office of helping the radial fibres in slackening the ligament and of steadying the action of the radial fibres.

The Canal of Stilling. When the eye-nucleus has been stained as I have described, there is generally no difficulty in seeing the posterior opening or openings of the canal, for the stain has probably penetrated some little way into the canal and has stained the membrane lining it. To merely shake the eye-nucleus in the stain will most likely cause the stain to enter, so that direct injection is unnecessary, especially if the suspensory ligament has been cut, for then the vitreus is quite flaccid, the pull of the vitreous fibres of the ligament having ceased, and so the stain readily enters. That it is the tension of the suspensory ligament which keeps the stain out of the canal is beautifully shown by the following experiment. When the posterior opening has been disclosed by the stain, the eye-nucleus meanwhile floating in water, it is easy to introduce a pipette and so inject picrocarmine or aniline dye solutions under pressure, the pipette being of a size to plug the canal and the pressure being exerted through a rubber tube from the mouth of the operator. Every time pressure is exerted the canal is filled, but, if the suspensory ligament is intact, so soon as the pressure is relieved the canal is more or less emptied again, while if the suspensory ligament had been severed and the vitreus had therefore become flaccid, it is much easier to fill the canal, and once filled it remains filled much more completely than when the ligament was intact. It is manifest that the intact ligament had maintained a tension of compression in the anterior part of the vitreus, which compressed the anterior part of the canal as soon as the pressure from the mouth was relieved, and so the stain was driven out. One can thus keep up a sort of flow and ebb of the injection fluid, which is alternately forced in by the pressure of the mouth and forced out by the pressure of the vitreus. The distended canal is sometimes seen to be bifurcate in front, not far from the back of the lens, a vestige of the dividing capsulo-pupillary vessels, but I have never found it in the ox eye to open in front through the floor of the fossa patellaris, which is always lined by the membrane described in a former paper and then described by Retzius as the boundary layer (Grenzschicht), composed of a condensation of the same fibrils as form the basis of the vitreus itself, and similar to the membrane lining the canal of Stilling. If, for instance, we take the figure of the horizontal section of the eye in *Quain's Anatomy*, 10th ed., fig. 45, " Organs of Senses," we see the canal put in with a broken line and ending anteriorly in a funnel-like dilatation behind the middle of the lens. This certainly does not apply to the ox eye, in which as I have said the canal never opens in front in the patellar fossa, so that in the ox the capsule of the lens is not bathed by the lymph of the canal of Stilling, nor is it in contact with the vitreous tissue proper. Between the lymph of the canal and the capsule of the lens there is always at least the patellar membrane and generally also some vitreous substance, and Henle, for instance, says that it ends blindly. It is easy to demonstrate the membrane over the whole of the floor of the patellar fossa and canal of Petit, Figs. 4 and 5. It can be punctured and lifted up quite easily in the fresh eye, Fig. 4. The edge of the puncture is sharp and the under surface of the raised portion is clean and well defined. Dissected off and tied over the end of a burette it supports a very considerable column of water, and I have mounted specimens in the museum that are in perfect order after some ten years. It is the presence of this membrane which permits removal of the lens in its capsule intact without prolapse of the vitreous substance. Where it lies free behind the canal of Petit this membrane has a thickened margin, Fig. 5, but where it is supported by its contact with the lens-capsule, a contact which it never leaves, it is thin, but everywhere over the fossa it is invariably present in the ox eye.

These observations have, I think, an important bearing upon our ideas as to the more intimate mechanism of accommodation. Essentially they confirm the teaching of Helmholtz, but they also extend his theory in an important particular, by giving a clue to what is probably a most important part of the act of accommodation, and, so far as I can learn, this clue, the function of the hyaloid canal, is new. Although the vitreous portion of the suspensory ligament has in itself no mechanism by which its tension can be altered, yet, being, through the capsular portion, joined to the ciliary portion, which *is* altered, the tension of the vitreous portion is thereby altered too. Further it is manifest that the varying strain of the vitreous fibres must be handed on still farther, viz. to the vitreous body itself. When the ciliary muscle contracts to slacken the suspensory fibres and thus permit the lens to bulge forwards, the lens-capsule pulls forwards the capsular portion of the ligament and through it the vitreous portion, and so through it again the ciliary zone of the vitreous body is pulled forwards and inwards. The anterior and central part of the vitreus is therefore more or less compressed, and the lymph of the canal of Stilling is squeezed out of the anterior part of the canal into the posterior part. But the movement which compresses the anterior part of the vitreus necessarily expands the posterior part of the canal. Thus the lymph is partly squeezed out of the anterior part and partly is sucked into the posterior part of the canal, widened to receive it. Conversely—when the ciliary fibres are tensed by the recoil of the choroid and the lens is flattened in negative accommodation the capsular portion of the suspensory ligament is pulled backwards and the vitreous part is slackened, permitting the ciliary zone of the vitreus to recede outwards and backwards, thus relatively dilating the anterior part of the canal, restoring it to its previous calibre, and compressing the posterior part. The function of the canal is thus to

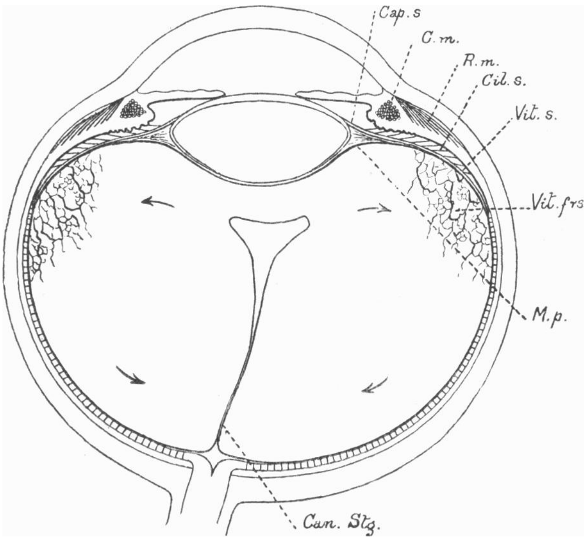


Fig. 8. Diagram of negative accommodation.

provide an adjustable reservoir of mobile liquid, which may be easily and rapidly displaced backwards in positive accommodation, forwards in negative accommodation. These movements are shown in diagrammatic form in Figs. 8 and 9. It need scarcely, perhaps, be pointed out that since the vitreous substance could not adjust itself readily to the pressure changes, some such mobile part is indispensable. The change in the position of the vitreous substance is propagated through the substance itself deeply: it is not a change merely travelling along the surface. My grounds for saying this are that the membrane lining the fossa patellaris is in the fresh eye invariably found adherent to the posterior capsule of the lens, and it is clear that, owing to this adhesion, there can be no actual movement of this portion of the surface of the vitreus on the capsule of the lens.

Hensen and Völckers found that in accommodation the retina moved with the choroid and therefore forwards in positive accommodation. This is just the direction in which I describe the vitreus to move,

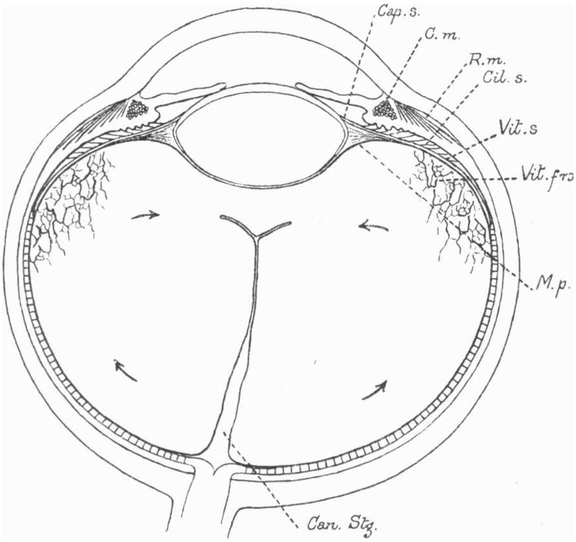


Fig. 9. Diagram of positive accommodation:
Cap. s., capsular portion of ligt. suspensorium.
Cil. s., ciliary fibres of ligt. suspensorium.
Vit. s., vitreous fibres of ligt. suspensorium.
C.m., circular fibres of ciliary muscle.
R.m., radial fibres of ciliary muscle.
M.p., membrane lining the patellar fossa and back of canal of Petit.
Vit. frs., fibrous membranes in the vitreus.

and so the friction of the hyaloid on the inner face of the inner limiting membrane of the retina is diminished, for rubbing only occurs if there is a difference in the movements of the retina and the vitreus. But the smooth hyaloid would easily glide on the smooth inner limiting membrane, and the fact that the posterior end of the canal is some distance away from the yellow spot would tend to diminish any possible mechanical disturbance of the latter. The foregoing account of the mechanism of accommodation would also account for the rise of pressure which caused the protrusion of vitreous substance through a puncture of the sclerotic and choroid during positive accommodation as noted by Hensen and Völckers. It is obvious that the effect of these changes in the vitreus is to avoid internal strains in the vitreus and its connections.

This subject seems to me to be interesting considered from the point of view of evolution, for the possession of a distinct function by the hyaloid canal would account for its long persistence as a vestige. Since the disappearance of the hyaloid blood vessels necessarily precedes the usefulness of the eye, the vessels probably disappeared, giving place to the canal, very early in phylogeny. One would think that there had, therefore, been ample time for the disappearance of the canal if it had been useless. That it persists argues for its having a use: its having a use has led to its persistence. And its ontogeny is what its phylogeny has been. In the fœtus the eye is not used—here the vessels are, but before the eye is used they disappear, giving place to the canal.

SUMMARY AND CONCLUSIONS.

A great distinction should be made between the functions of the fibres of the suspensory ligament which are attached to the ciliary bodies, &c., and the functions of those attached to the vitreous body. The former are virtually the tendon of the ciliary muscle; the latter are ligamentous in function, and (excepting the adhesion of its capsule to the membrane of the fossa patellaris) are the only means by which the lens is maintained in its place in the fossa patellaris during extreme positive accommodation, during eserinization, and in the eye-nucleus.

The tension of the vitreous fibres of the suspensory ligament is varied by varying tension of the capsular portion, which is directly under the control of the ciliary portion. This variation of the tension of the vitreous fibres is communicated to the antero-external zone of the vitreus, which is dragged forwards and inwards in positive accommodation: thus the lymph in the anterior end of the hyaloid canal is by compression emptied into the posterior end which by the same movement is widened. Conversely in negative accommodation the stretched choroid now recoils, pulls backwards and outwards the ciliary and capsular portions of the ligament, and so slackens the vitreous fibres that the antero-external zone of the vitreus recoils, the posterior end of the canal is compressed, and the anterior end widened to its previous calibre. The contents of the canal are thus a mobile liquid easily displaced to compensate for the movements of the non-liquid vitreus. In this way internal strains in the vitreus are prevented.

The possession of a distinct function by the hyaloid canal would account for its long persistence as a vestige, for the blood vessels probably disappeared, giving place to the canal, very early in phylogeny, so that there has been ample time for the disappearance of the canal if it had been useless.